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Sensitivity and uncertainty analysis on the criticality by an ERRORJ/SUSD3D with JENDL-3.3 covariance data

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Abstract. The covariance data processing and the nuclear data sensitivity and uncertainty analysis of the k_{eff} have been carried out for some 1-D benchmark problems by using the ERRORJ/SUSD3D code system. The uncertainties due to the U-233, U-235, U-238, Pu-239, Pu-240, and/or Pu-241 covariance data of JENDL-3.3 have been estimated with the P_3-S_{16} and P_3-S_4 approximations. The uncertainties amount to 0.53% ∼ 1.86% depending on the major actinides of the benchmark cores.

1 Introduction

For an accurate estimation of the nuclear data uncertainties in the nuclear integral parameters such as the k_{eff}, reactivity coefficients, isotopic inventories in a spent fuel, etc., covariance data should be included in the evaluated nuclear data files. However, covariance data is only available for a limited numbers of nuclides in the present evaluated nuclear data files. Recently, considerable efforts have been made for the generation and application of covariance data.

In this study, the covariance data processing and the nuclear data sensitivity and uncertainty analysis of the k_{eff} have been performed according to the procedures shown in figure 1. The uncertainties of the k_{eff} due to the U-233, U-235, U-238, Pu-239, Pu-240, and/or Pu-241 covariance data of JENDL-3.3 have been estimated for five 1D fast benchmark problems.

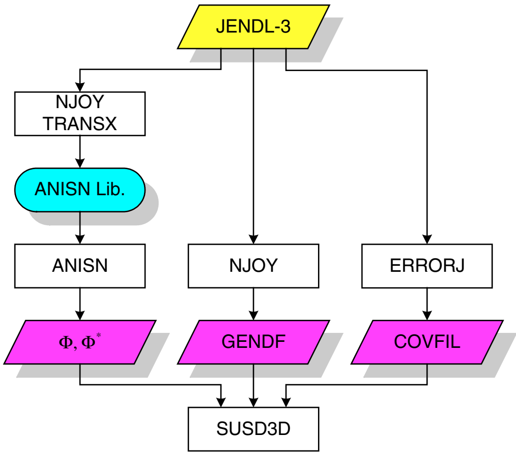

Fig. 1. Code system for the nuclear data sensitivity and uncertainty analysis.

2 Covariance data processing

Covariance data for the major actinides is necessary for applications to the nuclear data sensitivity and uncertainty analysis of criticality. Especially, the total fission (MT = 18) and total number of neutrons released per fission (total nu-bar, MT = 452 or MT = 455 + 456) should be prepared for that analysis. In view of the present goal, the JENDL-3.3 has a good stock of covariance data when compared with the other evaluated nuclear data files available.

The ERRORJ-2.2.1 code [1] has been used to produce the covariance matrices of U-233, U-235, U-238, Pu-239, Pu-240, and Pu-241 based on the JENDL-3.3. The LANL 30-group structure (IGN=3 of NJOY) [2] was adopted since it is useful for survey calculations for fast fission systems, fusion systems, and radiation shields. Figures 2 and 3 show the relative standard deviations (%) of the reaction cross sections of U-235 and Pu-239, respectively. They can provide the accuracy and reliability of the reaction cross sections in JENDL-3.3.

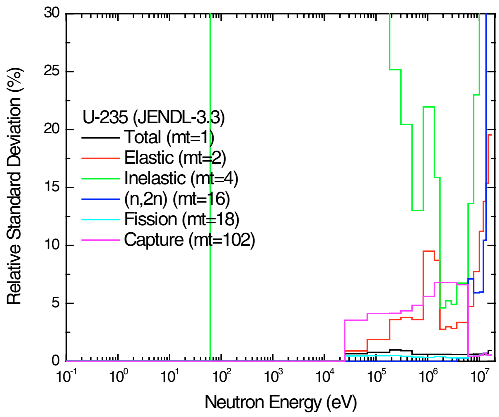

Fig. 2. Relative standard deviations (%) of the U-235 reaction cross sections.

In the case of U-235, the inelastic scattering cross section contains the largest uncertainties in most energy ranges above ∼60 eV. The uncertainties of the elastic scattering and (n,2n) reaction cross sections are significant in the fast energy region. In the case of Pu-239, larger uncertainties are shown for the inelastic scattering and capture cross sections in the energy

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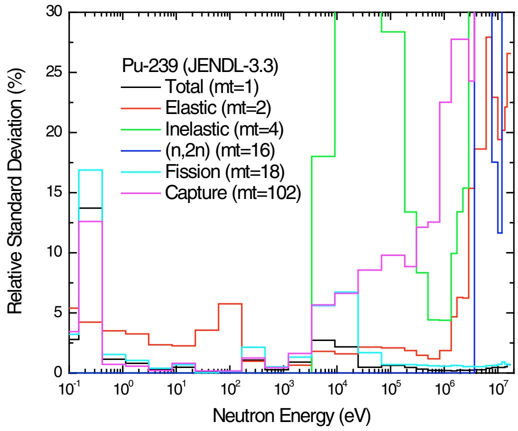

Fig. 3. Relative standard deviations (%) of the Pu-239 reaction cross sections.

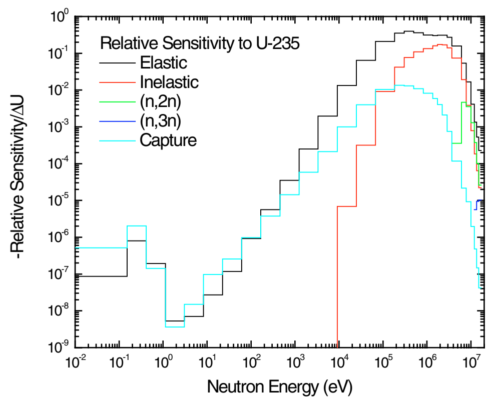

Fig. 4. Negative relative sensitivity of k_{eff} to the U-235 cross sections for GODIVA.

ranges above ~3 keV and for the elastic scattering and (n,2n) reaction cross sections in the energy ranges above ~3 MeV.

3 Sensitivity and uncertainty analysis of the criticality

The nuclear data sensitivity and uncertainty analysis of k_{eff} has been performed for five 1-D spherical benchmark problems, i.e., GODIVA, VNIIEF's Critical Test Facility (CTF), Pu-239 JEZEBEL, Pu-240 JEZEBEL, and U-233 JEZEBEL [3]. The JENDL-3.3 was processed by the NJOY99.90 [2] and ERRORJ-2.2.1 codes to generate the group-wise ENDF (GENDF) files and 30-group covariance matrices, respectively. The forward and adjoint fluxes were obtained from the ANISN [4] calculations with the P_3-S_{16} and P_3-S_4 approximations. The ANISN-format, problem-dependent, macroscopic cross section libraries were prepared by the NJOY99.90/TRANSX [5] codes. Finally, the SUSD3D [6] code was utilized for the sensitivity and uncertainty analysis.

3.1 GODIVA

The GODIVA experiment was performed at Los Alamos in the 1950's to determine the critical mass of a bare sphere of highly

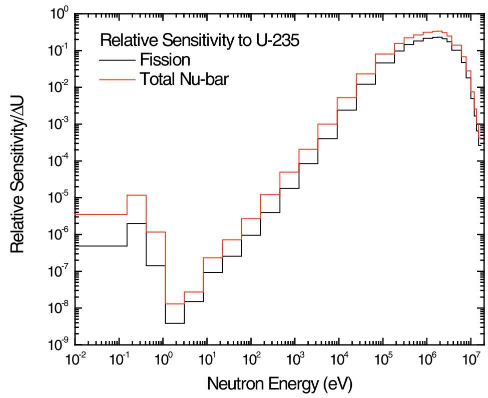

Fig. 5. Positive relative sensitivity of k_{eff} to the U-235 cross sections for GODIVA.

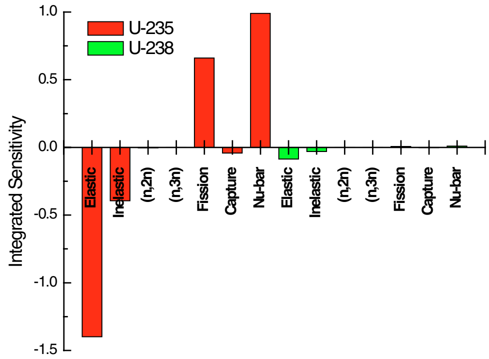

Fig. 6. Integrated sensitivity of k_{eff} to the U-235 and U-238 cross sections for GODIVA.

enriched uranium (HEU), which had isotopic abundances of 93.71% for U-235, 5.27% for U-238, and 1.02% for U-234. Figures 4 and 5 show the relative sensitivity of k_{eff} to the U-235 cross sections for GODIVA. The elastic and inelastic scattering cross sections are highly and negatively sensitive in the fast energy region, while the fission and total nu-bar cross sections are positively sensitive. The relative sensitivities of k_{eff} to the U-238 cross sections amount to 1/10 ~ 1/100 of those to the U-235 cross sections.

Figure 6 shows the integrated sensitivities of k_{eff} to the U-235 and U-238 cross sections. For GODIVA, the U-235 cross sections became more sensitive to the k_{eff} calculation than for U-238. Especially, the elastic scattering cross section of U-235 can provide the largest uncertainties to the k_{eff} calculation. As a result, the uncertainty of the k_{eff} due to the U-235 and U-238 covariance data of JENDL-3.3 was evaluated to be 1.283% (calculated k_{eff} = 1.00448) for P_3-S_{16} and 1.285% (calculated k_{eff} = 1.01356) for P_3-S_4.

3.2 VNIIEF's CTF

Criticality measurements of bare metal uranium assemblies, which had isotopic abundances of 36.5% for U-235, 63.1% for U-238, 0.3% for U-234, and 0.1% for other constituents, were conducted at VNIIEF's CTF in Russia in 1994.

As shown in figure 7, the U-238 cross sections became more sensitive to the k_{eff} calculation than U-235. Especially,

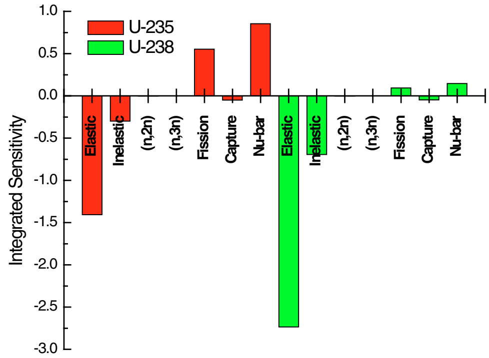

Fig. 7. Integrated sensitivity of k_{eff} to the U-235 and U-238 cross sections for VNIIEF's CTF.

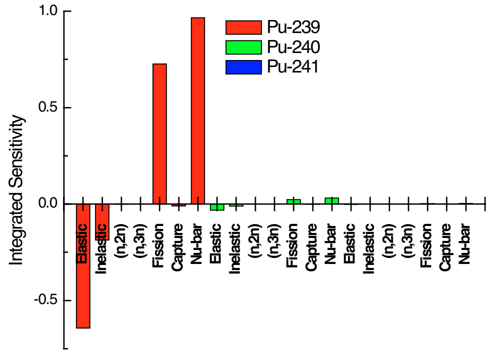

Fig. 8. Integrated sensitivity of k_{eff} to the Pu-239, Pu-240, and Pu-241 cross sections for Pu-239 JEZEBEL.

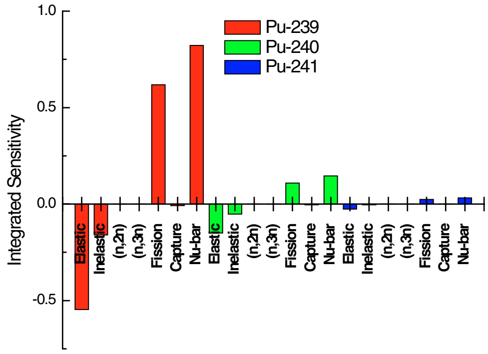

Fig. 9. Integrated sensitivity of k_{eff} to the Pu-239, Pu-240, and Pu-241 cross sections for Pu-240 JEZEBEL.

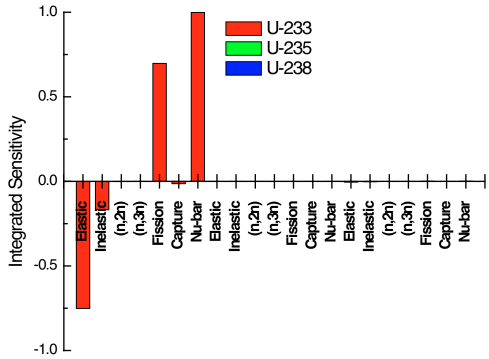

Fig. 10. Integrated sensitivity of k_{eff} to the U-233, U-235, and U-238 cross sections for U-233 JEZEBEL.

the elastic scattering cross section of U-238 can provide the largest uncertainties to the k_{eff} calculation. It is noted that the magnitude of the sensitivity to the U-238 elastic scattering cross section is excessively large when compared with the other benchmark problems. As a result, the uncertainty of the k_{eff} due to the U-235 and U-238 covariance data of JENDL-3.3 was evaluated to be 1.858% (calculated k_{eff} = 0.99886) for P_3-S_{16} and 1.856% (calculated k_{eff} = 1.00355) for P_3-S_4.

3.3 Pu-239 JEZEBEL

The Pu-239 JEZEBEL critical assembly was operated at Los Alamos in the early 1950's. The core had isotopic abundances of 95.2% for Pu-239, 4.5% for Pu-240, 0.3% for Pu-241, and 1.02% for Ga.

As shown in figure 8, the Pu-239 cross sections became more sensitive to the k_{eff} calculation than Pu-240 and Pu-241. Especially, the fission and total nu-bar cross sections of Pu-239 can provide the largest uncertainties to the k_{eff} calculation. As a result, the uncertainty of the k_{eff} due to the Pu-239, Pu-240, and Pu-241 covariance data of JENDL-3.3 was evaluated to be 0.546% (calculated k_{eff} = 0.99559) for P_3-S_{16} and 0.547% (calculated k_{eff} = 1.00899) for P_3-S_4.

3.4 Pu-240 JEZEBEL

The Pu-240 JEZEBEL critical assembly was operated at Los Alamos in 1964. The core had isotopic abundances of 76.4% for Pu-239, 20.1% for Pu-240, 3.1% for Pu-241, 0.4% for Pu-242, and 1.01% for Ga.
Although the enrichment of Pu-240 was increased by 20.1%, the Pu-239 cross sections were still more sensitive to the k_{eff} calculation than Pu-240 and Pu-241, as shown in figure 9. Especially, the fission and total nu-bar cross sections of Pu-239 can provide the largest uncertainties to the k_{eff} calculation. In this study, Pu-242 was not taken into account because of an absence of its covariance data in JENDL-3.3. However, it is expected that a small amount of Pu-242 has insignificant effects on an uncertainty estimation. As a result, the uncertainty of the k_{eff} due to the Pu-239, Pu-240, and Pu-241 covariance data of JENDL-3.3 was evaluated to be 0.534% (calculated k_{eff} = 0.99886) for P_3-S_{16} and 0.534% (calculated k_{eff} = 1.01186) for P_3-S_4.

3.5 U-233 JEZEBEL

The U-233 JEZEBEL critical assembly was operated at Los Alamos in 1961. The core had isotopic abundances of 98.13% for U-233, 1.24% for U-234, 0.03% for U-235, and 0.60% for U-238.

As shown in figure 10, the U-233 cross sections became more sensitive to the k_{eff} calculation than U-235 and U-238. Especially, the fission and total nu-bar cross sections of U-233 can provide the largest uncertainties to the k_{eff} calculation. As a result, the uncertainty of the k_{eff} due to the U-233, U-235, and U-238 covariance data of JENDL-3.3 was evaluated to be

1.065% (calculated k_{eff} = 1.00509) for P_3-S_{16} and 1.069% (calculated k_{eff} = 1.01714) for P_3-S_4.

4 Summary and conclusions

The covariance data processing and the nuclear data sensitivity and uncertainty analysis of the k_{eff} have been carried out for five benchmark problems by using the ERRORJ/SUSD3D code system with JENDL-3.3 covariance data. The estimated uncertainties due to the major actinide cross sections were not related to the number of discrete angles, as expected. In addition, the uranium cores had a tendency to produce larger uncertainties than the plutonium cores. Especially for the VNIIEF's CTF with great quantities of U-238, the uncertainty increased up to 1.86%.

This study could help us to assess the reliability of the reaction cross sections and/or their covariance data in the JENDL-3.3. For example, it reminds us that the elastic scattering cross section of U-238 reveals excessively large uncertainties to the k_{eff} calculations. Thus, thorough investigations into the covariance data of U-238 in the JENDL-3.3 are recommended.

For several years, multi-group cross section libraries such as the KAFAX, KASHIL, etc. have been generated and distributed to the nuclear research and development groups in Korea. While requests for improvements of the libraries become more important, there is also a need to quantify the nuclear data uncertainties for their calculations. The uncertainty estimations due to the libraries will be assigned for a future work.

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